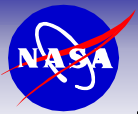


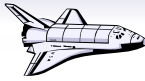
Thermal Protection System (TPS) Return-to-Flight Activities

Steve M. Poulos, Jr.
Orbiter Project Office
September, 2003





Five Levels of Crew/Vehicle Protection

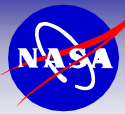


1. **Eliminate/minimize debris sources**
2. **Improve/develop inspection capability**
3. **Define TPS impact tolerance**
4. **Develop TPS repair capability**
5. **Evaluate ISS to keep the crew safe until they can be returned to Earth**

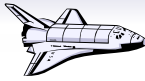


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TPS RTF Activities Comprise Hardware Processing, Impact Testing, and Model Development

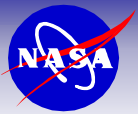


- **Both Tile and Reinforced Carbon Carbon (RCC) for STS-114 Will Complete Their Normal Turnaround Flow Processing**
 - RCC panels will also be subjected to non-destructive evaluation (NDE) to look for potential hidden damage such as cracks, voids, delaminations, or sub-surface oxidation.
- **Analytical Models Will Be Developed to Predict Damage to Tile or RCC**
 - Basic material properties testing will provide data necessary for model development
 - Impact test results will verify the model predictions
- **Impact Testing Will Be Performed on Both Tile and RCC to Determine the Damage Threshold**
 - Tile impact tests will be performed on acreage tile, carrier panels, and door edge tile configurations
 - RCC impact testing will be conducted on coupons and full-scale panels

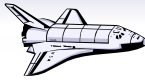


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Tile Turnaround Processing

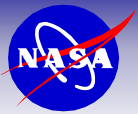


- **Tile RTF Preparation Will Meet All Turnaround Requirements and Include All Processing Verifications**
 - Complete Visual TPS inspection for damages/discrepancies
 - Nose Landing Gear Door (NLGD), Main Landing Gear Door (MLGD), External Tank Door (ETD) perimeter tile and Leading Edge Support Structure (LESS) Carrier Panel (C/P) tile/previous repair integrity inspection
 - Elevon Cove Leak Check verification
 - MLGD environmental seal contact verification
 - Perform all lower surface flow path inspections
 - ET Doors
 - MLGD
 - NLGD
 - LESS C/P's
 - Chin Panel C/P's

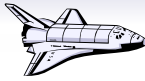


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RCC Turnaround Processing

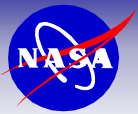


- **RCC RTF Preparation Will Meet All Turnaround Requirements and Include All Processing Verifications**
 - Step and gap evaluation (alignment)
 - Spar fitting shimming to original build condition
 - Panel/tee clevis fitting, shear fitting and spanner beam fitting shimming to per-print gap requirements
 - Addressed all spar corrosion issues and hole thread mark issues
 - Visual inspection of RCC for pin holes
- **RCC Panels Are Also Undergoing NDE to Look for Potential Damage or Degradation Not Visible to the Naked Eye**
 - Ultrasound to look for delaminations and voids
 - Eddy Current to look for localized oxidation
 - X-ray to look for cracks
 - Thermography to look for delaminations or cracks

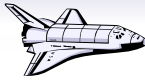


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RCC Turnaround Processing

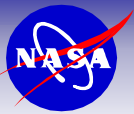


- **RCC Metallic Attach Hardware Is Being Subjected to NDE**
 - Visual to look for corrosion
 - Dye-penetrant and eddy current on Selected Components to Look for cracks/embrittlement

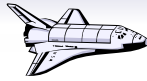


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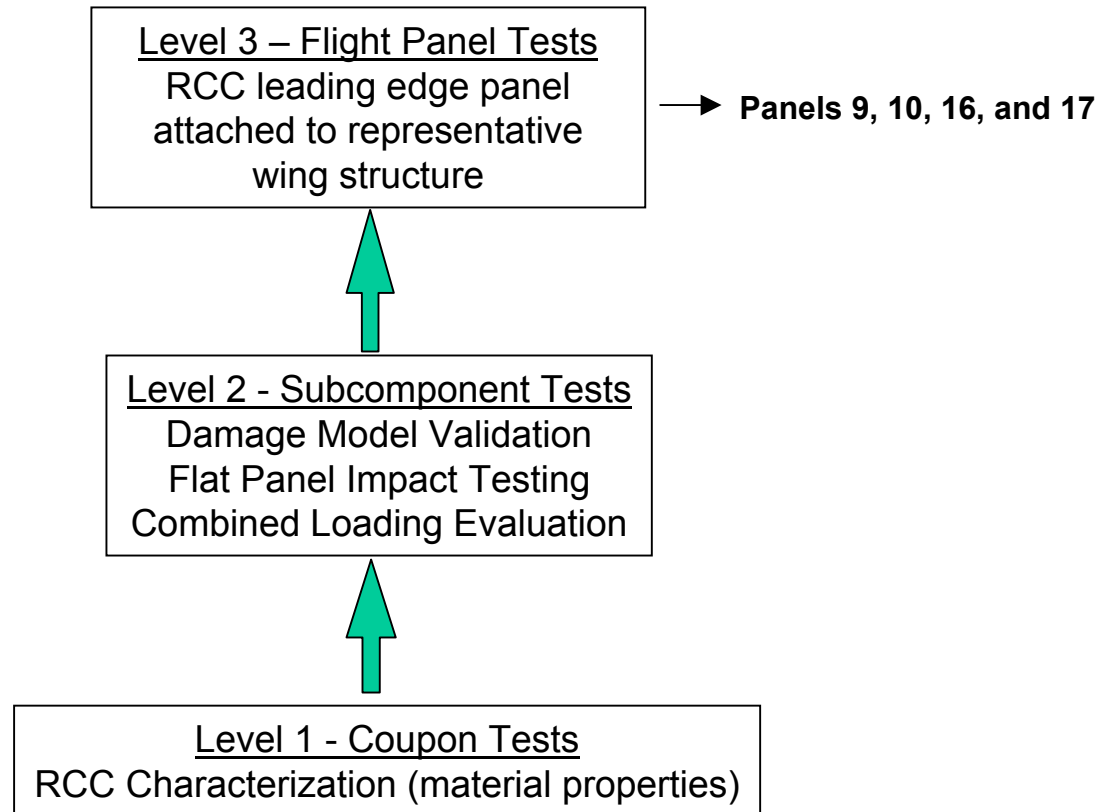


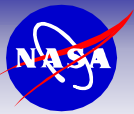


Analytical Model Will Be Developed to Predict Damage to RCC

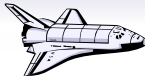


RCC Testing Plan Organized in a “Building-Block” Approach





Level 1 Coupon Tests Will Develop Basic RCC Material Properties

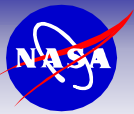


- **Material characterization program (strength, stiffness, stress-strain curves, fracture) to evaluate the effects of several variables:**

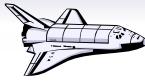
- Silicon Carbide (SiC) Coating
- High strain-rate
- Mass loss (max value = 0.03 lb/ft³)
- Laminate thickness (19-ply and 38-ply)



- **Test data will be used to update the material model input in the analytical tools used to predict impact damage (primarily LS-DYNA)**
- **NDE scans required on all coupons prior to testing**

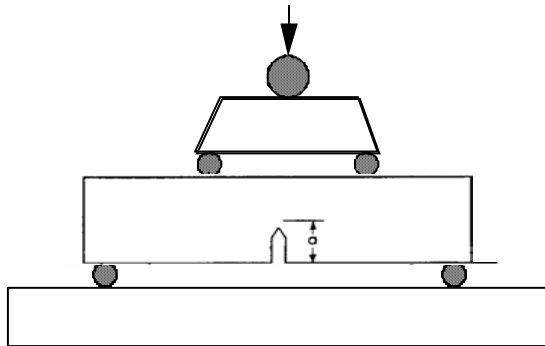


Level 1 Coupon Tests Will Develop Basic RCC Material Properties

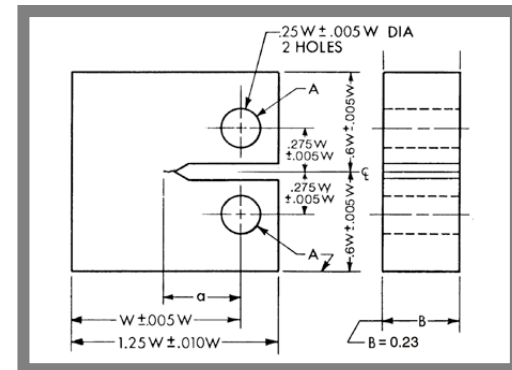


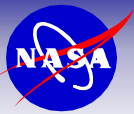
- Fracture property coupons – Goal is to determine critical fracture properties of RCC material for use in damage tolerance analysis

4-point toughness test – delamination mode

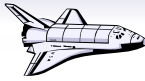


Compact Tension Toughness – through-thickness crack





Level 2 Flat Panel Tests Will Validate RCC Damage Model

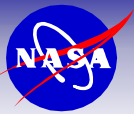


- **Level 2 Flat Panel Tests Will Validate the RCC Damage Model (LS-DYNA) and Determine the Threshold Between Acceptable and Unacceptable damage.**
 - Flat panel impact tests used to determine threshold of damage initiation
 - Follow-on structural tests used to determine threshold of acceptable damage (damage tolerance program to evaluate residual strength and damage propagation)
- **Phase A (RTF Critical): Initial Flat Panel Impact Tests Examine the Effects of Different Projectile Materials Corresponding to Most Likely Vehicle-Generated Debris Types:**
 - Foam (BX-265)
 - Ablator (select from Super Lightweight Ablator (SLA), Marshall Convergent Coating (MCC)-1, Booster Trowelable Assembly (BTA), others)
 - Ice
 - Metal (steel or aluminum)
- **Subsequent Tests (Phases B and C) Will Examine Variable Impact Angles, Projectile Sizes, and Velocities**
 - These tests are required for full model validation but not RTF
- **NDE Scans Required Prior to and After Testing (Ultrasound, Thermography, etc.)**

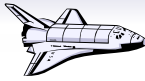


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Level 3 Full-Scale Tests Provide System Validation of the Analytical Model



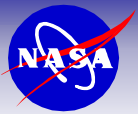
- **Level 3 structural testing approach**

- Supports model validation
 - Follows completion of Level 1 & 2 testing
 - Maximizes model validation developed in a building block approach
- Uses RCC assets: Panels #9, 10, 16, & 17
 - 2 foam impacts
 - 1 at low damage condition (below survivable damage threshold)
 - 1 at high damage condition (above survivable damage threshold)
 - 1 ablator impact at survivable damage threshold
- A two panel test configuration required
 - One target RCC panel/T-seal, & one real or fiberglass downstream panel
 - Wing spar structure may be present, but not required
 - Current analysis shows support structure is not critical
- Compare model predictions to test results

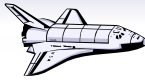


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RTF Tile Impact Testing



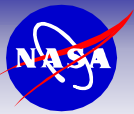
- **Objectives:**

- Generate test data to support the development of a refined analytical impact model
 - Characterize threshold velocity and total damage
 - Available debris sources and tile types
 - Characterize damage scatter
 - Characterize benefit of densified layer
 - Characterize effect of projectile orientation
 - Compare damage tolerance of new and aged tile types
- Characterize tile damage levels which have a potential for on-orbit repair
- Evaluate tile configurations sensitivity to available impact debris (MLGD, Carrier Panel)

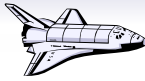


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Multiple Tile Impact Variables Need to Be Understood



- **Approach:**

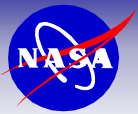
- Refined tile damage models will be established for most prevalent debris sources
 - Foam and ice constitute the spectrum of debris hardnesses
 - Lockheed Insulation (LI)-900 tile most sensitive to impact
- Remaining variables will be inserted at various points in the testing to support model correlation
 - Additional foam types
 - Ablators including MCC1,SLA,Cork
 - Metal
- Existing and proposed tile types will be evaluated
 - LI-2200, Fiber Reinforced Composite Insulation (FRCI)-12, Boeing Reuseable Insulation (BRI)-20 and BRI-8

- **Total number of shots required expected to be ~1000 for the program**

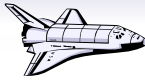


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Phase I Tile Impact Testing



- **Phase I Objectives:**

- Characterize LI-900 with foam impactors on main landing gear doors and wing acreage test articles at Southwest Research in San Antonio
- Square and rectangular foam cross sections will be utilized
 - Will characterize damage caused by foams (North Carolina Foam, Inc., BX-265, Polymer Development Lab)
- Impact aged tiles versus new
 - Determine if damage is greater for aged tiles
- Determine if densified layer remains for through-the-thickness damage

- **Phase I Parameters:**

- Particle sizes chosen to bound expected debris
- Angles chosen to bound impacts on lower surface

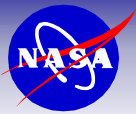
- **Initial Velocities Chosen to Create Damage**

- Velocities will vary and be defined by test results

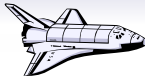


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Phase II & Phase III Tile Impact Testing



- **Phase II**

- Testing evaluates ice, metals and ablators on LI-900 substrate
- LI-900 Tile Repairs

- **Phase III**

- Test alternate tile configurations
 - MLGD edge tile
 - Carrier panels
- Test alternate tile types (BRI 20, FRCI)
 - Impactors include foam, ice, metal and ablators



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